

MOMENTUM TRANSFER FROM OBLIQUE IMPACTS. P.H. Schultz, Dept. of Geological Sciences, Brown University, Providence, RI 02912, D.E. Gault, Murphys Center of Planetology, P.O. Box 833, Murphys, CA 95247.

Background: The transfer of momentum during an impact and the fraction of impactor momentum that can change the angular momentum of a planetary body affects the spin rates of asteroids and comets as well as the evolution of angular momentum for larger planetary bodies (Earth-Moon, Venus?). Most existing data describe momentum transfer from impacts into brittle material, thereby resulting in large spall fragments (1,2,3). This may not be an appropriate model since asteroid surfaces probably have a regolith and since sufficiently large events result in shock comminution prior to excavation. Consequently, use of granular targets provide a better analogy for large events. Moreover, recent experiments revealing significant vaporization at low impact angles (4) would lead to the prediction of a momentum component in the opposite sense, i.e. uprange. A completely satisfactory experiment would be in a low gravity environment where the effect of momentum imparted by ejecta impacting the surface can be removed or controlled from momentum transfer during impact (5). Nevertheless, preliminary estimates can be made using a ballistic pendulum. Such experiments were initiated at the NASA-Ames Vertical Gun Range in order to examine momentum transfer due to impact vaporization for oblique impacts, but during calibration, intriguing new results have been obtained for non-volatile targets.

The impact experiments involved a physical (compound) pendulum using a small sand-filled target free to swing on a platform suspended by four wires. The targets consisted of No. 24 sand and dry-ice blocks/powder; the projectiles included aluminum, lexan, pyrex, and pyrex clusters. Impact velocities ranged from 1 to 8 km/s with impact angles from 15 to 45°. An apron surrounding the pendulum (but not attached) decreased the effects of momentum added by the deposition of ejecta. Successive mylar diaphragms minimized any possible effect of muzzle blast. A high frame-rate (200 fps) video camera system provided both vertical and side real-time views and was complemented by a higher resolution film record at 400 fps.

Results: Initial analysis reveals that the measured efficiency of momentum transfer (target-momentum/impactor-momentum) for 15° impacts is typically below 12% at hypervelocities ($> 4\text{km/s}$), a value significantly lower than the 50% - 100% commonly cited (2,6). This surprisingly low efficiency is largely the result of the impactor ricocheted downrange as previously documented (8,9). Aluminum witness plates positioned downrange from the point of impact recorded both the dispersion and angle of ricocheted fragments and are currently undergoing analysis in order to determine the total energy lost by this process.

Momentum transfer efficiency (k) appears to decrease with increasing velocity: from 12% at 3 km/s to less than 8% at 6 km/s from 0.635 cm-diameter aluminum spheres. Preliminary data further indicate that the value of k increases with impact angle: about twofold from 15° to 30°. This trend is consistent with the observation that less projectile material is ricocheted downrange with increasing impact angle. There also may be projectile size and density effects where decreasing projectile size and density increases k ; however, additional experiments are necessary.

Finally, easily volatized target material appears to increase downrange momentum transfer although this effect may yet be due to other factors. Momentum transfer typically is initiated prior to completion of crater formation (~ 100 ms) and, therefore, before ejecta emplacement. However, there consistently appears to be a very small uprange component immediately (<10 ms) after impact.

Discussion and Implications: The preliminary results indicate that momentum from oblique impacts is very inefficient: decreasing with increasing impact velocity and perhaps size; increasing with decreasing density; and increasing with increasing impact angle (from horizontal). At face value, such results minimize the effect of momentum transfer by grazing impacts; the more probable impact angles of 30° would have a greater effect, contrary to the commonly held impression. The process of momentum transfer, however, may involve two opposing components. Although the asymmetric distribution of ejecta during emplacement imparts momentum downrange, the ejection process should result in an initial momentum component uprange prior to emplacement. A small uprange motion has been tentatively identified, but the inertia of the ballistic pendulum is relatively large. The dominating effect of subsequent ejecta emplacement can mask this brief uprange component. On planetary bodies where the near-rim ejecta are retained (small bodies or large events on large bodies), momentum transfer is likely to be less than 10%. It is conceivable, however, that momentum transfer for small objects may not only be less than 10% but even in a negative sense. Consequently, until these competing responses have been defined, we must approach applications with caution.

Further experiments are necessary in order to confirm the observed preliminary trends and to test the limits of application. Ongoing complementary studies of ejecta distribution for oblique impacts (9) may help to resolve the competing roles of ejection and ejecta emplacement. Controlled experiments under a low-g environment, however, would permit evaluating the effects in absence of ejecta emplacement and more subtle phenomena damped by pendulum systems yet relevant to producing angular momentum in planetary objects.

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